Compensation of robot hand position using vision sensor

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***Abstract* - In order to locate a robot hand accurately, a vision sensor play a key role by measuring relative position. In our system, we assume that two 5-DOF manipulator fit a bolt and nut in cooperation. However, a vision sensor on a hand can not measure the position of an object which is grasped by the hand. In this method, a vision sensor is installed on the hand of each robot, and then measure a position of the hand and the object each other. Finally, each vision sensor compensate hand position each other.**

1. Introduction

The conventional industrial robot is suitable to repeated work based on the teaching play back. However, in the case of the off-line work based on CAD or so called intelligent system, difficult problems occur such that there are some errors between planned trajectory based on an internal model and actual trajectory. In such work, it is necessary to develop some sensor for recognising an error. Several calibration method[1]-[7] using vision , ultrasonic and so on have been developed up to date. Additionally, a method which directory correct the hand position using vision sensor with no calibration are reported..

Thus, In order to locate a robot hand accurately, a vision sensor play a key role by measuring relative position between a hand and an object. We have developed a compact vision sensor[8] which is easily installed on a hand of a robot. However, when several robots work in cooperation, a vision sensor on a hand can not measure the position of an object which is grasped by the hand because of dead angle and oclusion.

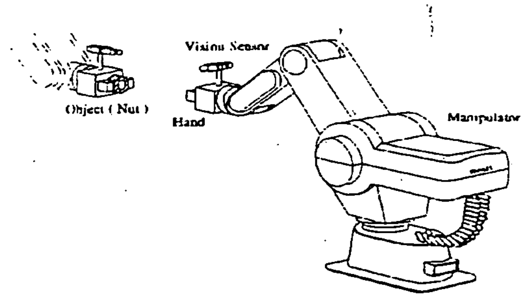

Fig.1 Experimental set up of the system

In this paper, we propose a novel method for measuring a relative position between a hand and an object using a vision sensor which is installed on a hand of the other robot. Using the vision sensor, we can improve depth measurement accuracy.

2. Definition of a task and model

In this experiment, we assume that two 5-DOF manipulators fit a bolt and nut as shown in fig. 1. A vision sensor is installed on a hand of each robot, and then measure a position of the hand and the object each other. **Fig. 2** shows the coordinate systems defined on each joint of the manipulators. A position vector ${}^{H}\boldsymbol{r}$ on the object which is grasped by other robot is transformed into the sensor coordinates using next equation.

$$ {}^{S}\boldsymbol{r} = \underbrace{{}^{S}T_H\, {}^{H}T_4\, {}^{4}T_3\, {}^{3}T_2\, {}^{2}T_1\, {}^{1}T_B\, {}^{B}T_W}_{Manipulator\ 1}\, \underbrace{{}^{W}T_B\, {}^{B}T_1\, {}^{1}T_2\, {}^{2}T_3\, {}^{3}T_4\, {}^{4}T_H}_{Manipulator\ 2}\, {}^{H}\boldsymbol{r} \qquad (1) $$

Where ${}^{i}T_j$ is a homogeneous transformation matrix between coordinates i and j. Usually, the Denaveit-Hartenberg method is used for describe the model, but, in our method, we use the homogenous transformation matrix.

Actually, there are several errors, for example parameter identification error, deflection of manipulator arm, backlash and so on, so it is difficult to correct the positioning error by the conventional method.

3. Principle of compensation.

The vision sensor which is used in this method is composed of multiple beam projector and CCD camera. This sensor can get a gray scale image and discrete range data at same position.

3.1 Model description

In the case of object recognition in actual environment, it is convenient to use model data of an object. In this method, we use the list structure for describing an object as shown in **fig.3**. This model describes a reliability factor R_i in addition to face, vertex and point, because reliability of edge extraction is influenced by edge condition such as a rounded edge.

3.2 Process of gray scale image

In this paragraph, process of gray scale image is described. First, gra-

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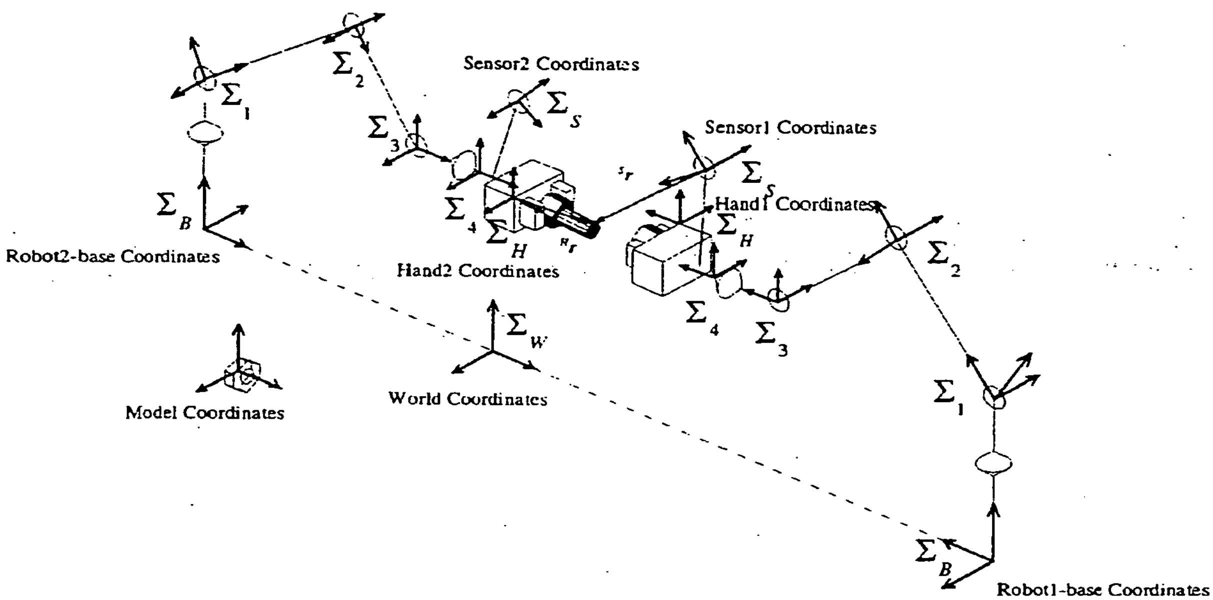

Fig.2 Coordinate system define on each joint.

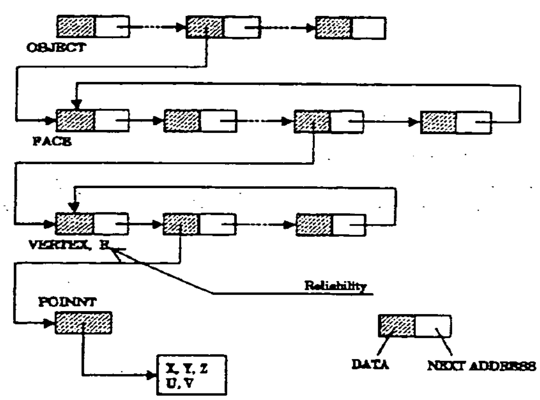

Fig.3 List Structure of Object Data

dient vector of two images which differ in lighting position are extracted. Next, model data are projected into image plane of the CCD camera using nominal parameter of the robot configuration. As shown in fig.4, a processed area is restricted under a condition that it is near area from an edge of the model and has same gradient values of the model. And then, extracted edges are fit into line and intersecting points are calculated using these lines.

3.3 Compensation of hand position

Position u of the model on the image plane of the sensor is calculated by next equation.

$$u = {}^{im}T_S\,{}^{S}r \tag{2}$$

where

$${}^{im}T_S = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1/f & 0 \end{bmatrix}$$

and f is focal length of the sensor.

However, because of kinematic errors of the robot, we add a matrix for compensating these error.

$$u = {}^{im}T_S\,T(q)\,{}^{S}r \tag{3}$$

where $q^T = [\,x\ y\ z\ \alpha\ \beta\ \gamma\,]^T$ is translation and rotation along X Y and Z axes. If there are some errors Δu between u and measured position, and the Δu is assumed that Δu is caused by the $T(q)$, then Δu is calculated by next equation

$$\Delta u = J\,\Delta q \tag{4}$$

where J is jacobi matrix defined by next equation.

$$J = \frac{\partial u}{\partial q^T} \tag{5}$$

Using an inverse matrix of this J and measured Δu, hand position is compensated.

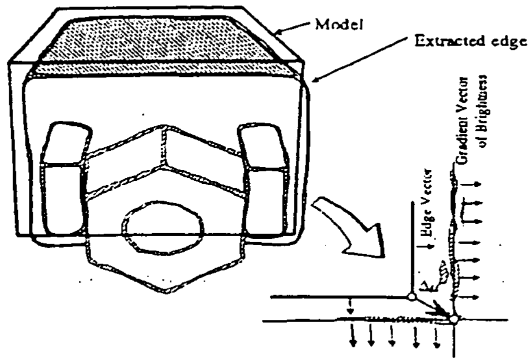

Fig4 Model Edge

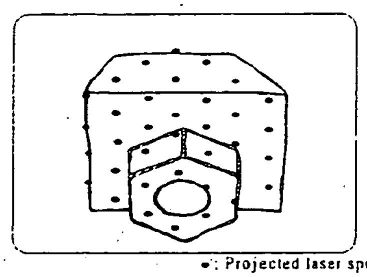

Fig.5 Model Fitting

As shown in **fig. 5**, image data are obtained by the vision sensor in the task assumed in our experiment. Using this image, error Δu is calculated.

First, edges are extracted using a model data as mentioned in **3.2**. Comparing the calculated point with the model, Δu is calculated. Reliability of extracted edges are depend on edge length. So we define a reliability factor A_i according to edge length

Additionally, in the case of rounded edge, reliability is low no matter what edge length is enough. Therfore, we define a factor R_i in the model data.

Using these factor, factor w_i calculated using next equation

$$w_i = A_i \cdot B_i \qquad i = 1,\cdots,n \tag{6}$$

And then, weight w_i is normalized using next equation

$$w_i = w_i \Big/ \sum_n w_i \qquad i = 1,\cdots,n \tag{7}$$

Using this weight w_i, equation (4) is extended into as follows

$$\begin{bmatrix} w_1\Delta u_1 \\ w_2\Delta u_2 \\ \vdots \\ w_n\Delta u_n \end{bmatrix} = \begin{bmatrix} w_1 J_1 \\ w_2 J_2 \\ \vdots \\ w_n J_n \end{bmatrix} \Delta q \tag{8}$$

Finally, error parameters are calculated using next equation

$$\Delta q = J_w^{\;+} \begin{bmatrix} w_1\Delta u_1 \\ w_2\Delta u_2 \\ \vdots \\ w_n\Delta u_n \end{bmatrix} \tag{9}$$

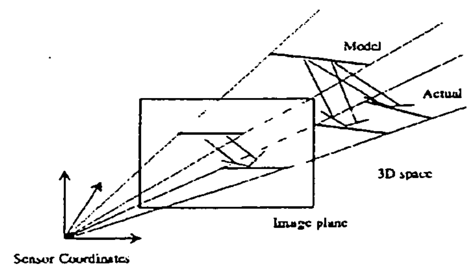

Fig .6 Fitting on Image Plane

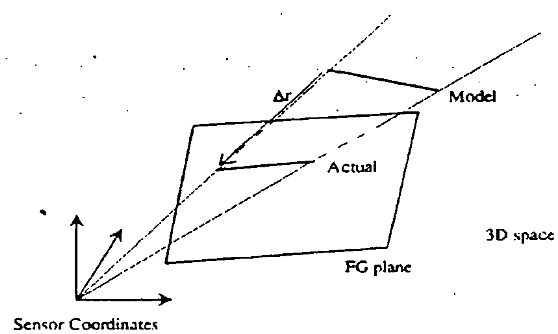

Fig.7 Fitting to Extracted Plane.

where, $J_w^{\;+}$ is pseudo inverse matrix according to the weight w_i.

The robot hand position can be compensated using this Δq.

3.4 Use of discrete range data

To improve an accuracy of depth measurement, we use the discrete range data obtained by the sensor. **Fig. 5** is illustration of input image

when multiple laser beams are projected. As shown in **fig. 6**, when an edge line is extracted, position error between model and an object is corrected into the plane which includes origin point of the sensor coordinates and edge line, so we can not expect high measurement accuracy of depth. In our method, we improve the depth accuracy using spot images shown in **fig. 5**. Three Dimensional range information is obtained from the spot image. First, FG plane parameters are estimated by the Least Mean Square method using spots which are on a surface of the object. And then, Candidates obtained by the method mentioned above are fit into the FG plane as shown in **fig. 7**.

4. Experimental results

An object used in this evaluation is a block with a size of 30 mm. Measurements are done at total of hundred positions which are in an area of 25 mm³. Errors of these measurements are indicated in **fig.7,8,9 and 10. Fig.7 and 8** show the error obtained by the gray scale image only and **fig. 9 and 10** is the image and discrete range data. These results say that distribution of depth (measurement error of Z-Direction) is improved from 10mm to about 1mm. **Fig.12** shows the model image which is superimposed on the hand and nut image. Before the compensation, these do not fit each other, but after the compensation, they fit mutually. Thus performance of the proposed method is verified.

4. Conclusion

In this paper, we have shown the method of compensation of robot hand position using vision sensor installed on the hand. Additionally, we show the performance of the method by the actual experiment.

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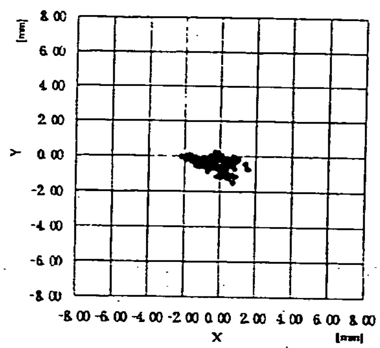

Fig .8 X-Y distribution of measurement error difference (Gray scale image)

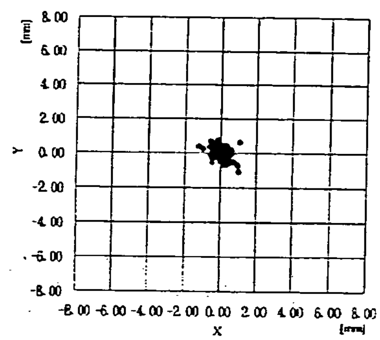

Fig .10 X-Y distribution of measurement error difference (Gray scale image and discrete range data)

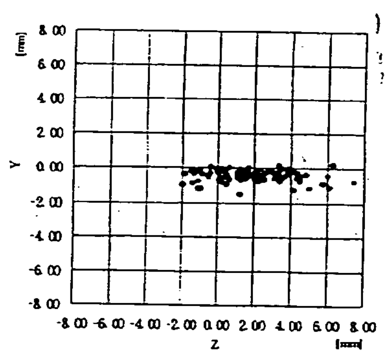

Fig .9 Z-Y distribution of measurement error difference (Gray scale image)

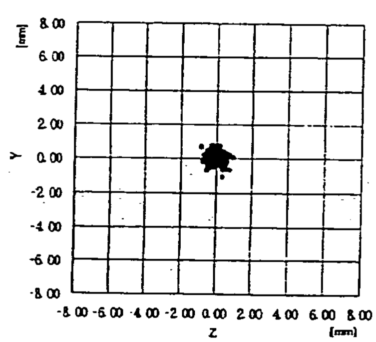

Fig .11 Z-Y distribution of measurement error difference (Gray scale image and discrete range data)

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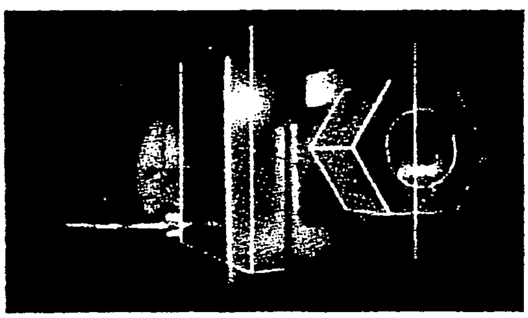

Fig .12 Before Fitting

Fig .13 Fitting with 2D and 3D Data